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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

AN EVALUATION OF SEVERAL TECHNIQUES FOR REDUCING CABLE STRUM

by

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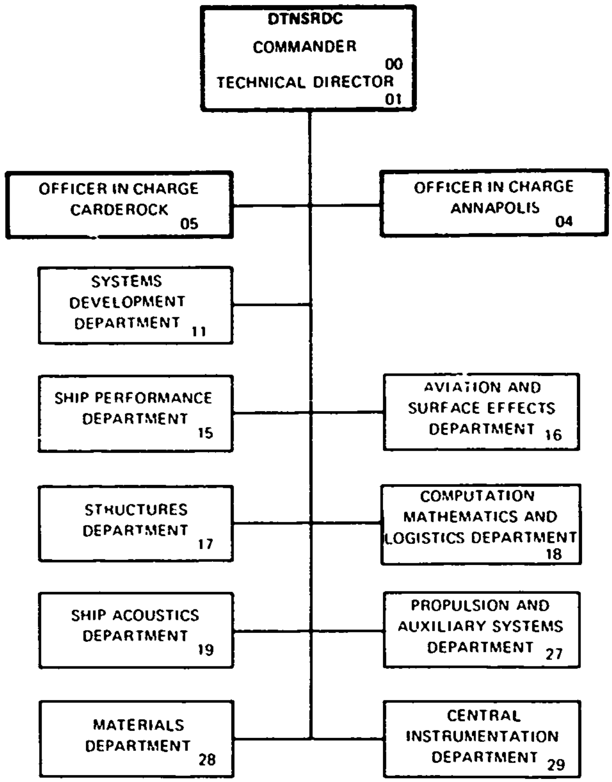

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20. ABSTRACT (Continued)

The cable was 0.53 inches (135 mm) in diameter and was 18.5 feet (5.6 m) long. Under the experimental conditions, certain types of appendages were found to be almost useless. The more useful ones were helical wire wrap, ribbon fairing and a commercial strip fairing. All of these appendages cause a higher value of tangential drag than does bare cable, and a comparison of these drag values is made. As a result of the experiment a new method of strum reduction, called stub fairing, was found to have good strum reduction efficiency but with much less drag penalty than the ribbon and the commercial fairing.

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NOTATION

B	Spacing between groups of ribbons in multiples of the cable diameter
C	The fraction of the length of a cable occupied (or covered) by the SRD
C_G	The inter-group coverage afforded by a group of ribbons; i.e., the fraction of the total group length occupied by the ribbons
D	Cable diameter
d	Diameter of wire wrap
F	Component of tangential hydrodynamic force per unit length of cable
f	Frequency of vortex shedding
f_K	Frequency of cable vibration
G	Length of a ribbon group in multiples of the cable diameter
K	Index representing a particular cable harmonic
L	Cable length
ℓ	Length of a ribbon in units of cable diameter
N	Number of ribbons set side-by-side within a group
n	Multiple by which the bare cable Strouhal Number is shifted due to the presence of a SRD
P	Pitch length
S_n	Strouhal Number
s	Spacing between ribbons in multiples of the cable diameter
T	Tension at the bitter end of a towed cable
T_o	Static tension
V	Free stream velocity
V_K	Free stream velocity for excitation of the K-th cable harmonic
$\overline{V}$	Free stream velocity at which resonance is excited in a cable whose Strouhal number is nS_n
W	Ribbon width in units of cable diameter
w	Weight per unit length of a cable immersed in water
μ	Mass per unit length of cable, including added mass of fluid
ϕ	Angle of attack of cable measured from the horizontal
ϕ_c	Angle of attack of a freely trailed cable (critical angle)
SRD	Strum Reduction Device
HW	Helical Wrap

NOTATION (Continued)

R	Ribbon Fairing
S	Stub Fairing

ABSTRACT

The usefulness of various appendages in reducing towcable strum was experimentally investigated for a tow-cable inclined at fifteen degrees to the oncoming flow. This angle was chosen as being representative of angles occurring in sonar array towing where strumming is believed to be a significant contributor to low frequency self-noise in the array. The measure of the efficacy of the strum reduction is based on the relative levels of the transverse acceleration at the center of a taut cable with and without the strum reducing appendages. The cable was 0.53 inches (135 mm) in diameter and was 18.5 feet (5.6 m) long. Under the experimental conditions, certain types of appendages were found to be almost useless. The more useful ones were helical wire wrap, ribbon fairing and a commercial strip fairing. All of these appendages cause a higher value of tangential drag than does bare cable, and a comparison of these drag values is made. As a result of the experiment a new method of strum reduction, called stub fairing, was found to have good strum reduction efficiency but with must less drag penalty than the ribbon and the commercial fairing.

ADMINISTRATIVE INFORMATION

This research was conducted by the Towed Systems Branch of the David W. Taylor Naval Ship Research and Development Center under Work Units 1548-304 and 1548-212. The research was funded by the Naval Electronic Systems Command, PME-124, under Project Order 4-4646 of 29 December 1973 and by the Office of Naval Research, Code 222, under Project Order 4-0117 of 6 August 1973, under Program Elements 63794N and 62751N respectively.

INTRODUCTION

Under the joint sponsorship of the Office of Naval Research and the Naval Electronics Systems Command, the David W. Taylor Naval Ship Research and Development Center was tasked to establish the relative effectiveness of various devices to reduce the strumming of towcables used with flexible sonar arrays. The more effective of these devices will be evaluated during sea trials using a towed acoustic array.

Vortices shed coherently from a towcable generate transverse oscillations of the towcable at the vortex shedding frequency and longitudinal oscillations at twice the vortex shedding frequency. These waves travel along the towcable. If the towed device is an acoustic array the transmitted energy evidently contributes to the "self-noise" of the array hydrophones and may result in degradation of overall sonar performance. It is therefore important that the transmitted energy be rejected (as by appropriate cable terminations) or that the transverse excitation be reduced to tolerable levels. An evaluation of several techniques for accomplishing the latter comprises the subject matter of this report.

Various techniques have been used to reduce strum (and drag) of cables exposed to moving water. A short summary is given by Fabula and Bedore[1], who have investigated a particular technique that consists of wrapping a cable with a second one of smaller diameter, in the form of a spiral or helix. A survey of the literature concerned with vortex formation on circular cylinders, with emphasis on techniques for prevention, was accomplished by Diggs[2], as a prerequisite to the work reported herein. It was determined that four basic mechanisms may be used to control either the size or influence of the vortices. Briefly, these consist of controlling the width of the wake (as with a streamlined fairing), disruption of the periodicity of vortex discharge (as with splitter plates in the wake), prevention of spanwise coherence of the shed vortex, or simple interference with the vortex formation itself. To these may be added a fifth, namely, modification of the response characteristics of the cable. Obviously, the addition of appendages to a cable will modify both the flow and the cable response to some degree, so it is not possible to attribute precisely a given result to a single mechanism. However, the devices to be tested were selected on the basis of perceived interference with the spatial-temporal harmony between shed vortices and/or modification of the response characteristics of the cable.

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[1]Fabula, A. G., and R. L. Bedore, "Cable Strum Suppression Experiments with Helical Ridges," U.S. Navy Journal of Underwater Acoustics, Vol. 24, No. 4 (Oct 1974).

[2]Diggs, Jesse S., "A Survey of Vortex Shedding from Circular Cylinders with Application Toward Towed Arrays," Mar Inc., Tech. Report No. 122 (Jul 1974).

Appendages also modify the flow about the cable and thus change the hydrodynamic resistance. The components of hydrodynamic force normal and parallel to the cable are both affected. Thus the efficiency of an appendage must be judged with respect to its total effect on the cable.

To accomplish this, a typical towed array towcable with and without strum reduction devices (SRD's) was installed between two vertical struts at an angle to the flow representative of angles occurring in sonar array towing where strumming is considered to be a significant contributor to low-frequency self-noise in the array. The amplitude of the transverse oscillation of the mid-point of the towcable was measured for each SRD. Also, each SRD was towed on a freely streamed cable and the drag was measured.

This report presents the details of the experimental approach to obtain the strumming and drag characteristics of the SRD's and the bare cable, compares the effectiveness of each SRD in reducing the strum and the impact on drag, and provides conclusions and recommendations for at-sea evaluation of the concept.

APPROACH

The major problem in measuring vibration phenomena is to assure that the observed oscillations are excited only by the particular disturbance being investigated. The approach described below was designed to assure excitation of a resonant transverse oscillation of the bare cable by the shed vortices. This was done by matching the fundamental frequency of the test sample with the vortex shedding frequency. The amplitude of the resonance was expected (and found) to be much larger than that of vibrations excited by extraneous inputs, as from the supporting structure.

STRUM EXPERIMENT

A heavy string suspended between two points will oscillate at the frequencies defined by the equation

$$f_K = \frac{K}{2L} \sqrt{\frac{T_o}{\mu}} \qquad (1)$$

where

L is the length of the cable,

T_0 is the static tension,

μ is the total mass per unit length of cable

f_K is the frequency, and

K is the harmonic number.

If a periodic excitation is applied to the cable or to its supports, the cable will oscillate after the decay of transients at the frequency of the applied force with an amplitude that is a maximum when the fundamental and applied frequencies coincide. Successive maxima will appear as the disturbance frequency successively coincides with the various harmonics.

It is well established that the vortex shedding frequency of a cylinder is centered in a narrow band about the frequency given by the equation

$$f = \frac{S_n V \sin \phi}{D} \qquad (2)$$

where

S_n is the Strouhal Number

V is the stream velocity

ϕ is the angle of inclination to the flow, and

D is the cable diameter.

Equating these two frequencies and solving for the velocity V_K (i.e., the velocity at which the K-th harmonic is excited) yields

$$V_K = \frac{KD}{2LS_n \sin \phi} \sqrt{\frac{T_0}{\mu}} \qquad (3)$$

Thus, it is reasoned that a taut cable pinned at both ends and towed at the speeds V_K given by equation (3) will exhibit maximum displacements (or what is equivalent, maximum transverse accelerations) at its mid length for the odd harmonics. Hence a measure of the effectiveness of a strum reduction device (SRD) may be obtained by comparing the amplitude of the transverse acceleration of a bare, round cable at resonance with the amplitude at resonance when modified by the addition of a SRD.

It should be noted that the comparison is valid only when the SRD modified cable is towed under the identical conditions for which resonance was excited in the bare cable. This poses a danger in that if the SRD merely shifts the shedding frequency as expressed by the Strouhal Number to some new value, the speed $\bar{V}$ at which resonance would occur is thereby shifted to

$$\bar{V} = V_K/n$$

To provide reasonable assurance that this situation would be detected, the experiment was conducted (in the manner of reference 1) by accelerating slowly up to a speed of about twice the speed for resonance of the bare cable and thence decelerating slowly to zero speed.

TANGENTIAL DRAG

The tension T in a long cable towed at the critical angle[3] ϕ_c is given by

$$T = (w \sin \phi_c + F) L \tag{4}$$

where

F is the tangential component of the hydrodynamic drag per unit length, and

w is the immersed weight of the cable per unit length.

If the length and weight of the basic cable are not changed, a measurement of T at specific speeds of tow is sufficient to rank the cables in terms of relative drag. A selection of the strum-reduction models, which were of fixed length and weight, was therefore towed freely trailing, and the tension was measured at various speeds.

SELECTION AND DESCRIPTIONS OF STRUM REDUCTION DEVICES

A strum reduction device (SRD) typically consists of an appendage attached along the length of a cable, either continuously or with a repetitive pattern.

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[3]Pode, L., "Tables for Computing the Equilibrium Configuration of a Flexible Cable in a Uniform Stream," David Taylor Model Basin Report 687 (Mar 1951).

Ribbons and helical wrap (Fabula's "helical ridges") were identified in reference 2 as the mc t applicable SRD's for towed array towcables. Streamlined fairings were excluded due to the handling problems and the excessive tangential drag experienced at the shallow towing angles typical of towed array towcables. In the course of the evaluation a variation of the ribbon called "stubs" was evaluated. The remaining devices represented attempts to modify the disturbance and response characteristics of the cable.

The SRDs selected for evaluation are described in Appendix A where the models evaluated are listed in Tables A-1 through A-7. A commercial fairing selected for evaluation also is desc.ibed in Appendix A. The six basic devices selected for evaluation are listed below with a brief explanation of the reason for selection.

1. Ribbons - known to be effective for towcables at steep angles to the flow. They have not been evaluated at the small angles characteristic of array towcables.
2. Stubs - a variation of ribbon, selected for the handling advantages afforded and possible lower drag.
3. Helical wrap - evaluated previously, selected as a control and to extend the range of data available by applying them to flexible towcable.
4. Sleeves -
   a. Heavy sleeves - attempt to change response characteristic of the cable and the vortex shedding frequency over discrete lengths of the cable.
   b. Light sleeves - attempt to change vortex shedding frequency over discrete lengths of the cable by increasing the local cable diameter.
5. Rings - attempt to disrupt length-wise coherence of shed vortices.
6. A commercial fairing - reported to give good results on seismic-streamer towlines.

The description of an SRD varies with the type of device. A compact notation descriptive of the helical wraps, ribbons, strubs, etc. is developed in Appendix A. For brevity, the more important of the SRD's are hereafter identified by the following symbols:

HW	- Helical Wrap
R	- Ribbon
S	- Stub
RF/SF, or R/S	- Mixed Ribbon/Stub Fairings
SEC	- Seismic Engineering Corporation Fairings

"Rings" and "sleeves" are simply referred to by name.

EXPERIMENTAL EQUIPMENT AND PROCEDURES

The equipment and procedures used for the strum and tangential drag measurements are described in the following paragraphs.

STRUM EXPERIMENTS

The strum experiments were performed in the David Taylor Model Basin on the high speed carriage using the towing assembly illustrated in Figure 1. The cable model was suspended between two strut assemblies, the forward assembly consisting of twin struts set at a depth of 2 feet (0.6 m), and the aft one being a single strut set at a depth of 6.8 feet (2.1 m). The forward twin struts are connected at the lower end by a cross-strut to which the leading end of the cable model was attached. This arrangement resulted in the cable having a 15 degree inclination to the flow. The forward end of the cable was secured to the mid point of the cross strut via a universal joint and a ring gage dynamometer. The dynamometer was used to measure preload tension and tension fluctuations. The aft end of the cable was secured to a leader by means of a wire rope clip. The leader then passed over a 6-inch (150 mm)-diameter pulley, up through the aft strut, and was secured to a turnbuckle. The turnbuckle was tightened to apply a preload tension of 500 pounds (2200 N). Approximately halfway between the forward and after struts, a small ogive strut was used to pass electrical leads down to the accelerometer. An Endevco Model 2228C triaxial accelerometer, attached at the center of the cable, was used to measure accelerations along orthogonal axes transverse to the span of the cable. The accelerometer signals were amplified using an Ithaco 453 amplifier with a roll-off of 3 dB down at one Hertz. The vector sum

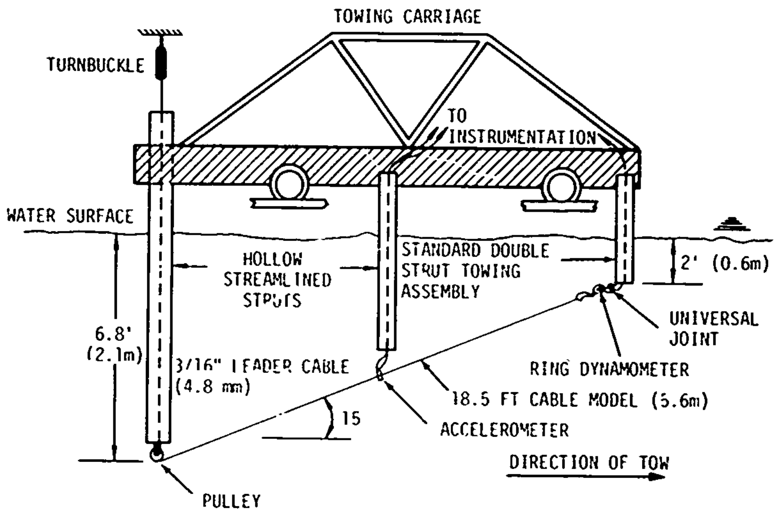


Figure 1 - Schematic of Towing Assembly for the SRD experiment

of the two acceleration signals was obtained using an Intronics Model VM101 vector operator and associated logic circuitry.

To obtain the measurements, the towing carriage was accelerated slowly from 0 to 5 knots (2.6 m/s) and then decelerated slowly to rest. Static tension, tension fluctuations, vectorial cable acceleration, and carriage speed were recorded on a Brush recorder and on magnetic tape. Data were recorded for the full duration of the run. Using this procedure, measurements were obtained for the bare (un-modified) cable, and then for each SRD modified configuration, in turn.

TANGENTIAL DRAG

The tangential drag experiments also were performed in the high speed basin. The towing assembly is illustrated in Figure 2. The tension link was a 100 pound (450 N)-capacity ring-gage tensiometer.

With the cable samples attached and freely trailing as illustrated in Figure 2, selected samples were towed at steady speeds of 5, 10 and 15 knots (2.6, 5.2 and 7.76 m/s). The output of the tensiometer was recorded for a finite interval of time after the carriage had steadied at the desired speed.

ANALYSIS TECHNIQUE

The data were reduced and analyzed in accordance with the procedures described in the following paragraphs.

STRUM EXPERIMENTS

The vector sum of the transverse acceleration components, as detected at the center of the cable model, was averaged over the interval of speed corresponding to the excitation of the resonance of the fundamental mode of the bare cable. The interval of speed over which resonance was strongly excited was 2.7 to 3.1 knots (1.4 to 1.6 m/s). In this interval of speed, a typical vectorially summed acceleration output, as recorded on the Brush recorder, exhibited a strong modulation, indicative of the presence of a beat frequency. This is typical of strum-induced vibrations. The averages therefore were taken as the means of the successive maxima of the modulated wave form.

An average of the averages was taken over several runs for the bare cable, and this average was used as the basis for comparison with the SRD

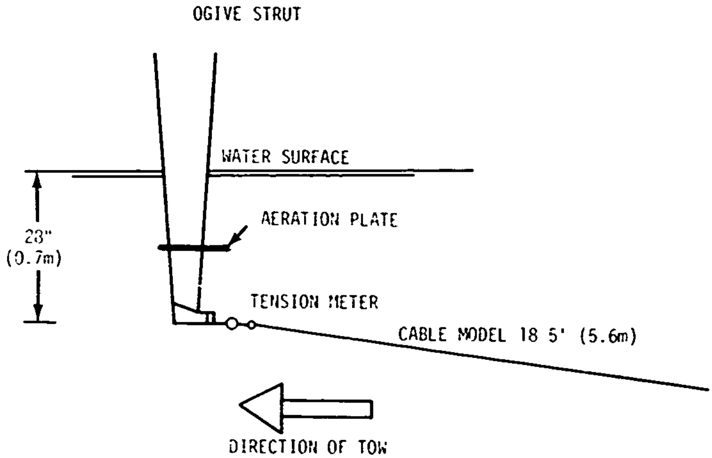


Figure 2 - Equipment Configuration for Tangential Drag Measurements

modified cables. The dispersion of the averages was found to be quite small, so that for most of the SRD modified cables the averages from a single run were used.

The ratios then were formed of the averaged transverse acceleration amplitudes of each SRD modified cable relative to the averaged transverse acceleration amplitudes of the bare cable. Finally, these ratios were expressed in terms of decibels (dB).

TANGENTIAL DRAG

The tension data for the bare cable and each SRD modified sample were simply recorded for the speeds of 5, 10 and 15 knots (2.6, 5.1 and 7.7 m/s). Ratios of the drag of the SRD modified cables relative to the drag of the bare cable were computed for each cable at the speeds of 10 and 15 knots (5.1 and 7.7 m/s).

STRUM REDUCTION RESULTS

The experimental technique for evaluating strum reduction was found to be sound. The bare-cable frequency response was found to be in excellent agreement with predictions based on equations (2) and (3), as illustrated below. The experimental configuration of the bare cable had the constants listed below (the cable is described in Table A-1):

$K = 1$

$D = 0.044$ feet (13.4 mm)

$L = 18.5$ feet (5.64 m)

$S = 0.18$ to 0.21

[illegible] = 15 degrees

$T_o = 500$ pounds (2224 N)

[illegible] = [illegible] (cable) + [illegible] (added mass) = 0.0162 slugs/ft (0.776 kg/m)

Using these values in equation (3), the speed at which resonance occurs is found to fall between 2.3 and 2.7 knots (1.2 and 1.4 m/s), corresponding to values of S of 0.21 and 0.18, respectively. The resonant frequency, from either equation (1) or (2), is found to be 4.75 Hz. These predictions proved quite accurate. The resonance started at about 2.4 knots (1.2 m/s) and the amplitude gradually increased to a maximum at a speed of approximately 2.8 knots through 3.1 knots (1.4 through 1.6 m/s).

These results indicate that the transverse vibrations of the cable were essentially unaffected by towing carriage vibrations or flexing of the support structure.

HELICAL WRAP

The helical wrap models tested are listed in Table A-5. The effect of helical wrap on the strum amplitude, relative to bare cable is shown in Figure 3. Figures 3a and 3b for a wrap diameter to cable diameter (d/D) ratios 0.36 and 0.24 indicate that maximum effectiveness occurs for a pitch-to-diameter (P/d) ratio of 15. This corresponds to a helix angle of 11.8 degrees. The maximum reduction ranges from about 11 to 13 dB. P/D ratios smaller and greater than 15 are less effective, but P/D of less than 15 is more effective than P/D greater than 15. It is noted that the effectiveness of the d/D = 0.12 wrap (Figure 3c) is greatly reduced relative to the two first discussed. Nevertheless, for the P/D's evaluated, the strum is reduced by the d/D = 0.12 wrap to between 1.5 and 2.6 dB (30% and 45%) that of the bare cable.

Figure 4 shows the effect of d/D for P/D = 15. No inferences can be drawn regarding the behavior in the range 0.12 < d/D < 0.24 as the onset of significant reduction may be quite sudden with respect to d/D.

Even the smallest reductions obtained represent an acceleration amplitude of about 3dB (50%) relative to the bare cable. The maximum reduction is 13 dB or about 95% relative to the bare cable. The optimum P/D is likely to be a function of the cable towing angle, hence general extrapolation of these results is not warranted.

Fabula reports that the most effective of the helical ridges evaluated in reference 1 give a reduction on the order of 25 dB. It is interesting to note that the most effective model was a single rounded ridge having a d/D of 0.26 as compared to the most effective ratio found in the present work of 0.24. Reference 1 also reports that the ridges were effective at both 20 and 10 degrees yaw and that a P/D of 10 was found most effective.

Little importance can be placed on the differences in strum-amplitude reduction reported here and by Fabula in reference 1, since the average resonant acceleration amplitude may have been greater for the reference

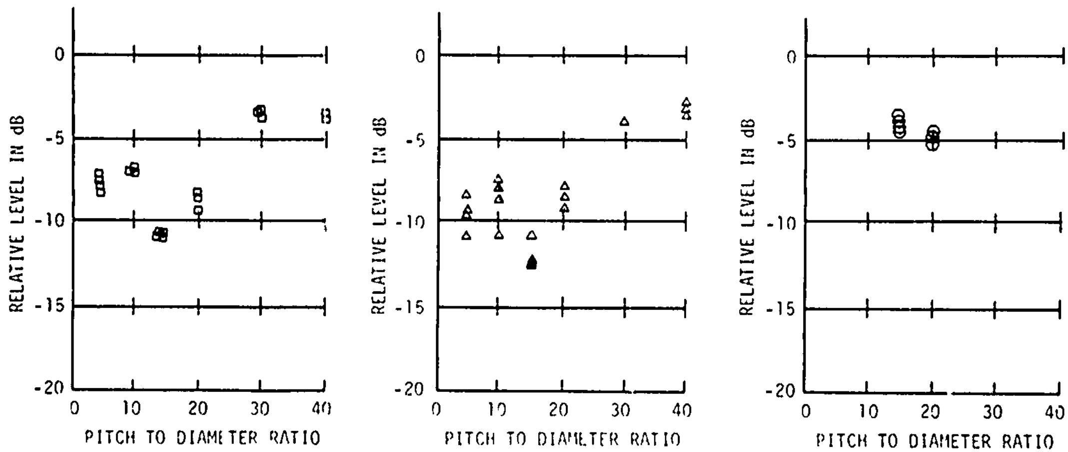


Figure 3a - d/D = 0.36

Figure 3b - d/D = 0 24

Figure 3c - d/D = 0.12

Figure 3 - Acceleration Levels of Helical Wrap Relative to Bare Cable

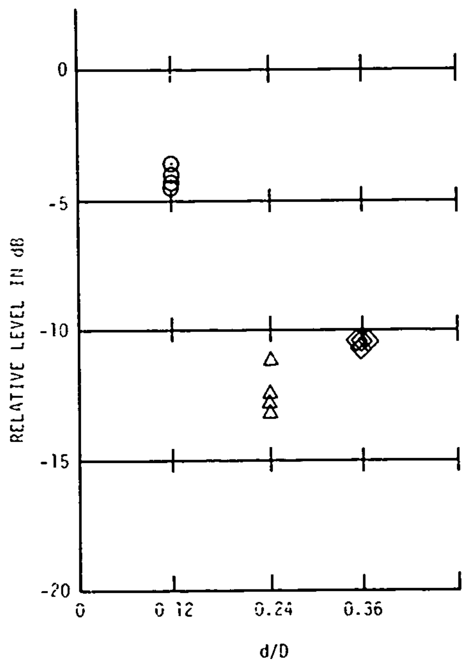


Figure 4 - Acceleration Levels of Helical Wrap Relative to Bare Cable for Helix Pitch-to-Diameter Ratic of 15

model. The importance of the additional reduction of hydrophone response is not known.

RIBBONS

The ribbon models are listed in Table A-2. The results for 1 x 4 and 1 x 6 ribbons* are shown in Figure 5. The reductions are slightly greater than those exhibited by the best helical wrap but do not, in general, exceed 15 dB. No significant difference is discernible between the two data sets, except that the 1 x 4 ribbon is apparently slightly superior for coverages of 50% and greater. The reduction is apparently proportional to percentage of coverage for coverages up to 25%; a small improvement accompanies coverages greater than 25%.

The results for the 2 x 6 ribbons are shown in Figure 6. The 2 x 6 ribbon gives essentially the same reduction as the 1 x 4 and 1 x 6, but the "knee" in the curve is shifted to 12.5% coverage versus 25% for the other two. This is significant as it indicates that the same results may be obtained with half of the material otherwise required. A slight improvement at 6.25% coverage also is seen relative to the 1 x 4 and 1 x 6 configurations.

STUBS

Stubs can be regarded as very short ribbons but are believed to function in quite a different manner. The models evaluated are listed in Table A-3. The strum reduction due to stubs is shown versus percentage of coverage in Figure 7. Effectiveness evidently increases in proportion to coverage (above some minimum coverage that is less than 25%) up to 75%. No data are available for coverages greater than 75%.

The trend is identical to that exhibited by the 1 x 6, 1 x 4 and 2 x 6 ribbons, except the decrease in strum with increase in coverage is not nearly as great and the maximum reduction is only about 50% that obtained with the long ribbons.

RIBBON/STUB COMBINATIONS

The 1 x 6 ribbon models were evaluated for the effectiveness of ribbon/stub combinations. The models evaluated are listed in Table A-4.

* See Appendix A for nomenclature

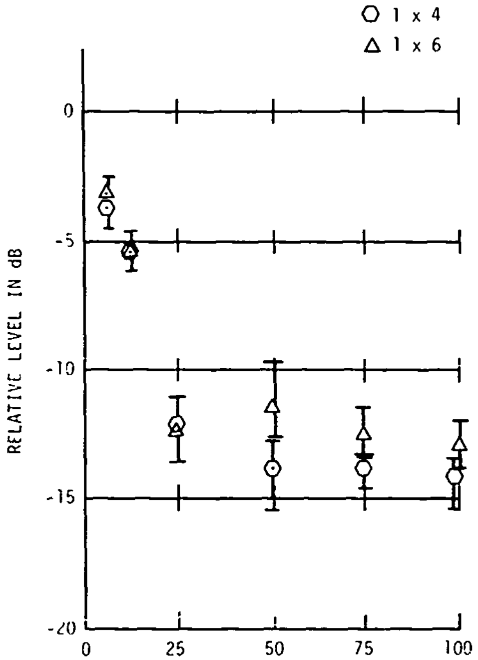


Figure 5 - Acceleration Levels of 1 x 4 and 1 x 6 Ribbons Relative to Bare Cable as a Function of Coverage

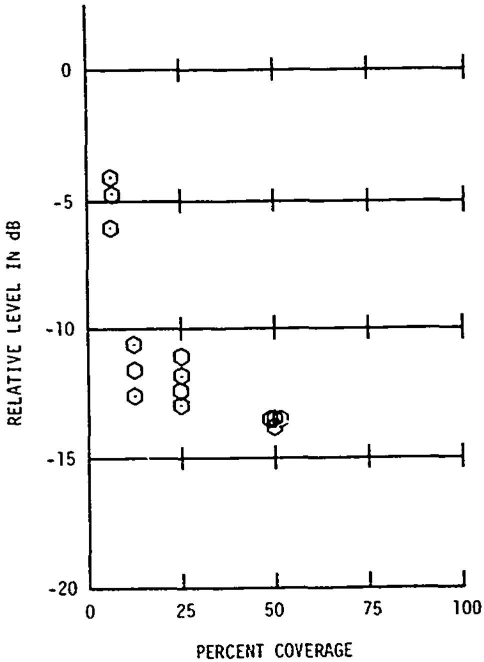
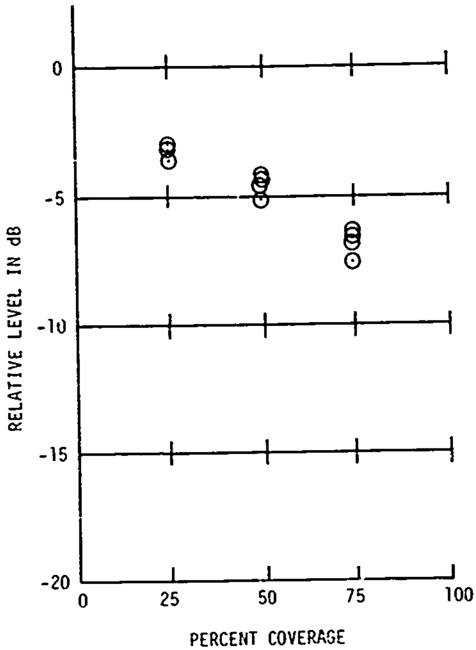


Figure 6 - Acceleration Levels for 2 x 6 Ribbons Pelative to Bare Cable as a Function of Coverage



Note: 100% coverage was not evaluated.

Figure 7 - Acceleration Levels of 1 x 1/4 Stub Relative to Bare Cable as a Function of Coverage

The 1 x 6 model started with a (3 x 1) pattern* for 75% coverage. The results are shown in Figure 8 and compared with the 1 x 6 results without stubs. The abscissa of Figure 8 indicates regular ribbon coverage in percent, followed by stub coverage in percent.

The 1 x 6 ribbon/stub combination shows some improvement relative to ribbons for coverages from 00/75 to 12.5/62.5. The strum at the "knee," 25/50, is evidently not improved by the presence of stubs. The 6.25/68.75 and 12.5/62.5 cases show improvement relative to ribbons only, but the improvement is 2 to 4 dB less than that shown by the 2 x 6 ribbon for 12.5% coverage (Figure 6).

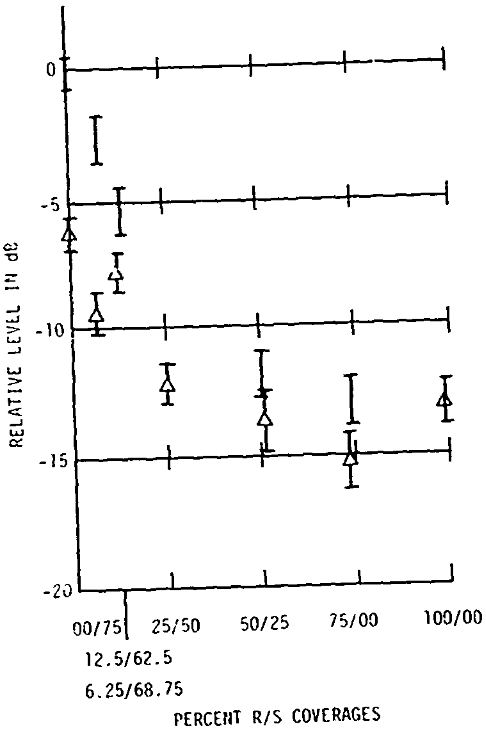
RIBBON GROUPS

Type I. A Type I group is one in which the coverage is 100% within the group and in which the groups are separated by gaps of bare cable. The models tested are listed in Table A-2. The results are shown in Figure 9. The abscissa in this figure indicates the number of diameters covered by the side-by-side ribbons followed by the interval in cable diameters from the initial point of one group to the initial point of the next. The ratio of the two numbers is the fractional coverage. The pattern of the strum reduction is similar to that seen before: i.e., a linear increase in effectiveness with coverage, followed by minor improvement as coverage increases above 25%. This is clearly shown by Figure 10, in which the effectiveness of a 1 x 6, Type I coverage is compared with the 1 x 6, regular coverage. No essential difference is discernible.

Type II. A Type II coverage is one in which the coverage is depleted from within the group. The models tested are listed in Table A-2, and the results are shown in Figure 11. The series starts with a 1 x 6 ribbon with a (12 x 0) (12 x 12) grouping.** That is, 100% coverage for 12 diameters, followed by a 12 diameter gap. It is thus the same as the 50% coverage model for the Type I groupings. We note a substantial improvement over the Type I group for the 12.5% coverage. The resultant strum

* See Appendix A for nomenclature

** See Appendix A for description of ribbon pattern notation



Note: XX/YY indicates ribbon coverage in percent followed by stub coverage in percent.

Figure 8 - Acceleration Levels of Ribbon/Stub Cable Relative to Bare Cable

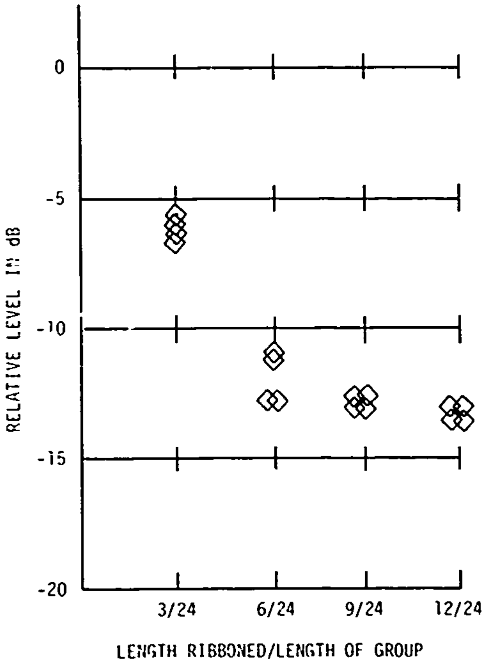


Figure 9 - Acceleration Levels of 1 x 6 Ribboned Cable Relative to Bare Cable for Type I Groupings

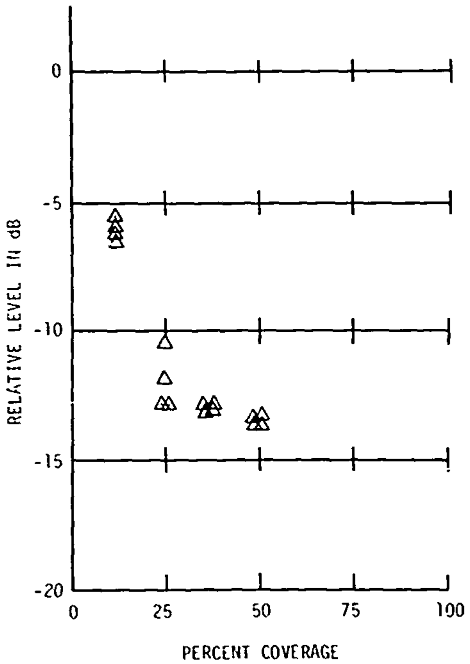


Figure 10 - Acceleration Levels of Ribbon Grouping 1D x 6D w/o Stubs - Type I Relative to Bare Cable

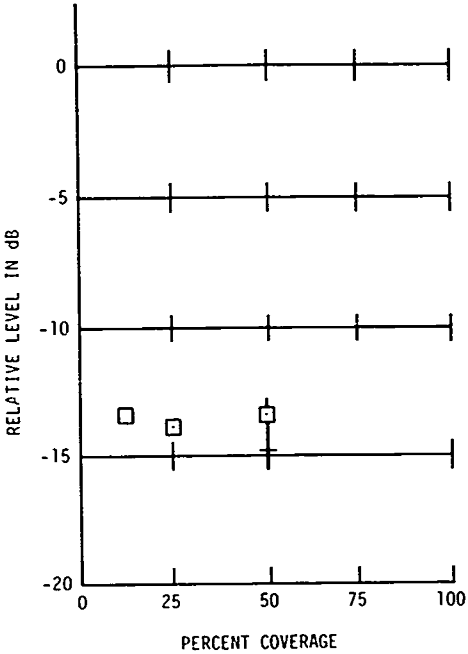


Figure 11 - Acceleration Levels of Different Types of 1D x 6D Ribbons - Type II Relative to Bare Cable

reductions are, in fact, essentially the same as those for the 2 x 6 ribbon results for 12.5% coverage and the 1 x 6 and 1 x 4 regular coverage results for a 25% coverage. We shall discuss this in more detail in a later section

SLEEVES

Sleeves are described in Appendix A, and a listing of the model evaluated is given in Table A-6. All sleeves are 3/4 inch in outside diameter (19 mm). The ratio of sleeve to bare cable diameters was thus 1.42. The "heavy" sleeves had a mass ratio (mass of cable + mass of sleeve + added mass)/(mass of cable + added mass of cable) of 3.25. The mass ratio for the "light" sleeves was 1.19. Results are shown in Figures 12a and 12b. The abscissa are in terms of diameters covered by the sleeve to the left of the slash, with the total length of cable (in diameters) between the repetition points to the right of the slash. The fraction, of course, is the fractional coverage. The results indicate a minor reduction in strum of about 2 to 4 dB. Apparently the change in diameter (and shift of Strouhal frequency) is the effective mechanism. Weight and percentage coverage appear to have no appreciable effect.

RINGS

Rings are described in Appendix A, and the models are listed in Table A-7. Results are shown in Figure 13. Rings were slightly less effective than sleeves. The effectiveness increased slightly for the closest spacings. Spacings of less than 7.5 diameters were not investigated.

SEISMIC ENGINEERING COMPANY FAIRING

The Seismic Engineering Company Fairing is described in Appendix A. This was the most effective SRD tested in terms of strum reduction. The acceleration measurements for the Seismic Fairing were not distinguishable from the ambient, and apparently produced a strum reduction in excess of 20 dB. The effect of depletion on the effectiveness of the Seismic Fairing was not evaluated.

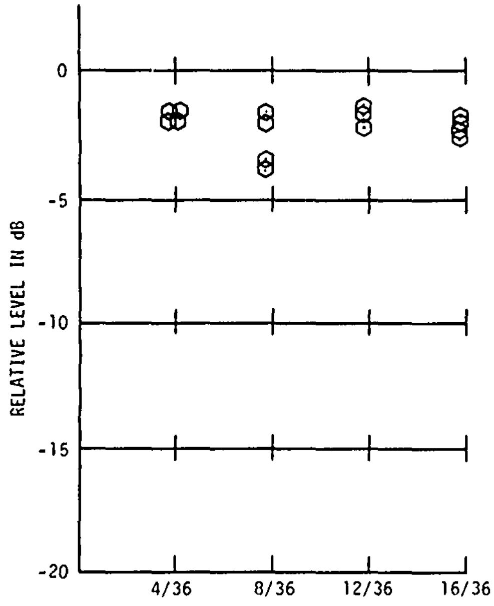


Figure 12a - Light Sleeves

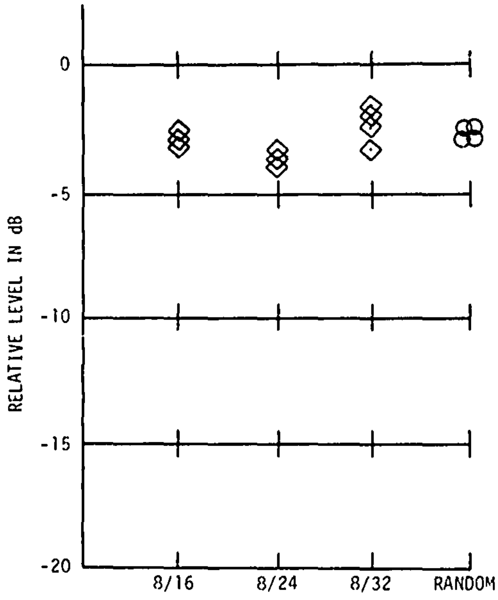


Figure 12b - Heavy Sleeves

Figure 12 - Acceleration Levels of Sleeved Cables Relative to Bare Cable

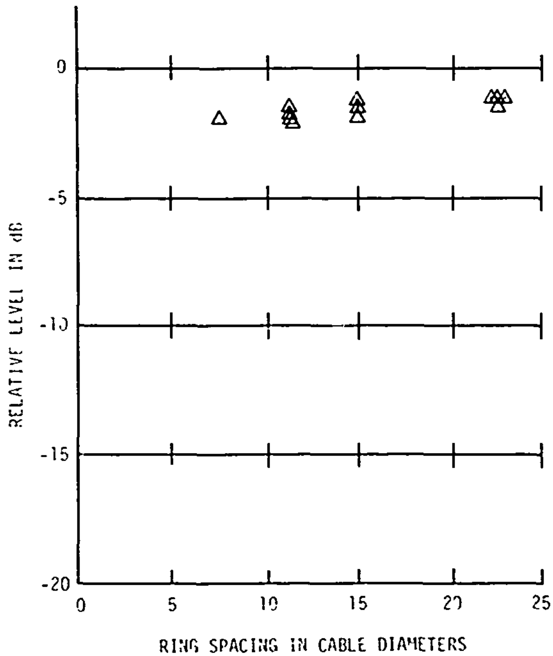


Figure 13 - Acceleration Levels of Ringed Cables
Relative to Bare Cable

TANGENTIAL DRAG RESULTS

The measured tensions in the models tested for tangential drag are listed in Table 1. Of the ribboned models, only the 1 x 6 was evaluated. Also, the only stubbed cable towed was the one with 75% coverage.

TABLE 1-TANGENTIAL DRAG OF SELECTED SRD MODIFIED CABLES

Type	Style	% Coverage	Tension in pounds (N) Speed in knots (m/s) 5(2.6)	10(5.1)	15(7.7)
SEC	Flexible Fabric	100	5.3(23.6)	19.1(85.0)	46.2(205)
RF	1 x 6	100	10.0(44.5)	21.6(96.1)	36.9(164)
RF	1 x 6	75	10.5(46.7)	19.1(85.0)	35.8(159)
RF	1 x 6	50	9.2(40.9)	20.2(89.8)	33.0(147)
RF	1 x 6	25	6.2(27.6)	17.3(77.0)	29.5(131)
RF	1 x 6	12.5	4.3(19.1)	14.0(62.3)	25.5(113)
RF	1 x 6	6.25	3.1(13.8)	12.2(54.3)	22.3(99.2)
SF	1 x 1/4	75	1.9(8.5)	10.5(46.7)	21.0(93.4)
HW	d/D=0.36, P/D=10	100	2.3(10.2)	7.2(32.0)	14.3(63.6)
HW	d/D=0.36, P/D=15	100	1.9(8.5)	5.9(26.2)	11.5(51.1)
HW	d/D=0.36, P/D=40	100	1.2(5.3)	5.0(22.2)	10.7(47.6)
HW	d/D=0.24, P/D=10	100	2.2(9.8)	6.0(26.7)	12.4(55.2)
HW	d/D=0.24, P/D=15	100	2.5(11.1)	5.5(24.5)	10.7(47.6)
HW	d/D=0.24, P/D=20	100	2.0(8.9)	6.0(26.7)	11.3(50.3)
HW	d/D=0.24, P/D=30	100	1.9(8.5)	5.7(25.4)	10.8(48.0)
HW	d/D=0.24, P/D=40	100	1.0(4.4)	4.7(20.9)	9.6(42.7)
HW	d/D=0.12, P/D=15	100	1.3(5.8)	4.3(19.1)	9.0(40.0)
Bare	-	-	1.0(4.4)	3.9(17.3)	7.8(34.7)

DISCUSSION

A direct correlation between self-noise and strum is not available. Thus, it is not possible to predict self-noise reduction on the basis of the present evaluations. In particular, the degree of diminution required to reduce the hydrophone output noise to levels limited by flow noise and ambient is unknown. At this time, it can only be conjectured that the lower the vibration amplitude, the more likely it is that a noise reduction will ensue.

Several aspects of the data deserve comment. It is noteworthy that for the ribbon type SRD's, the initial strum reduction (in decibels) is essentially a linear function of the coverage up to about 25% coverage. Some improvement is gained by increasing the coverage, but the improvement is not substantial. The general nature of the relation is illustrated in Figure 14. The position of the knee typically formed at about 25% coverage is not very sensitive to ribbon distribution. The approximate initial slope and position of the knee for the ribbons are contained in Table 2 for Ribbons and Stub Faired Cables.

TABLE 2 - POSITION OF KNEE IN ACCELERATION LEVELS VERSUS COVERAGE CURVES

SRD TYPE	SLOPE dB/%	POSITION of KNEE in %	MAXIMUM REDUCTION in dB
RF 1 x 6			
RF 1 x 4	0.5	25	13-14
RF 1 x 6 Type I			
RF 1 x 6 Type II	0.8	12.5	12-13
RF 2 x 6			
SF 1 x 1/4	0.1	75*	7

* No Knee for Stubs - Data not available for coverage greater than 75%.

No significant difference is found for the 1 x 6 Type I and 1 x 4 ribbons; therefore, if the shortest ribbon that provides equivalent reduction is considered optimum, it is obvious that the optimum length ribbon lies between 1/4 (stubs) and 4. On the basis of the 2 x 6 ribbon results it appears that an optimum width may exist which may be greater than two.

Note also that a 1 x 6 Type II coverage produces better results than a 1 x 6 Type I coverage, i.e., roughly the same benefit is gained for a 1 x 6 Type II coverage as accrues to the 1 x 6 regular coverage but with

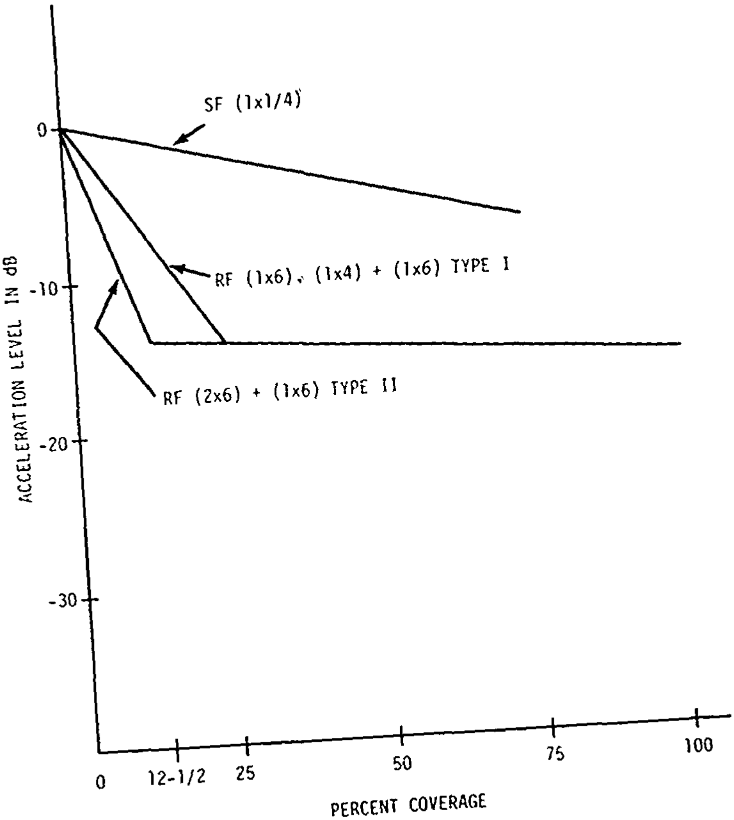


Figure 14 - Comparison of Strum Reduction Trends for Stub and Ribbon Fairways with Regular and Group Type Coverages

one-half the ribbons. This would suggest that if a 25% coverage is to be designed, it should be either a 2 x 6 (1 x 6) or a 1 x 6 (1 x 1) (12 x 12), as loss of up to 50% of the ribbons in either arrangement would result in no significant loss of effectiveness.

Helical wrap was not evaluated relative to effectiveness versus percent coverage. Limited exploration of this subject with one model is contained in reference 1 and found that effectiveness (for a P/D of 10) began to diminish for coverages of less than 75%. Also, it is interesting to note that the d/D ratio found most effective in the present series was essentially the same as that found in reference 1; 0.24 versus 0.26.

In general, the strum reduction effectiveness of the ribbons and helical wraps that gave the best results were essentially identical, being 11 to 13 and 11 to 14 dB down, respectively. The best stub fairing gave only about one-half the reduction obtained with the best ribbon and helical wrap. Of course, it is recalled, the Seismic Engineering Fairing gave the greatest strum reduction of all those evaluated.

SUMMARY OF STRUM REDUCTIONS

The approximate reductions in strum are summarized in Table 3 in order of effectiveness. The Seismic Engineering Corporation Fairing was clearly superior to all other candidates. The helical wrap and ribbon candidates are essentially equivalent. Of the ribbon candidates, the 2 x 6, 12.5% and 1 x 6 Type II, 12.5% grouping are best if minimum coverage is desirable.

TANGENTIAL DRAG

In Table 4 the SRD modified cables are ranked in order of decreasing relative drag for the two highest towing speeds.

The ratio of the tangential drag of the SRD modified models to that of the bare cable is shown in Figure 15. Figure 15a shows the relative drag values of the ribbon, stubs and Seismic Engineering Corporation Fairings plotted against percentage coverage for the 10-knot (5.1m/s) and 15-knot (7.7 m/s) towing speeds. The same data for the helical wraps are plotted as a function of P/D in Figure 15b. The 5-knot (2.6 m/s) data are not considered representative due to the fairly steep towing angles that accompany that speed of tow.

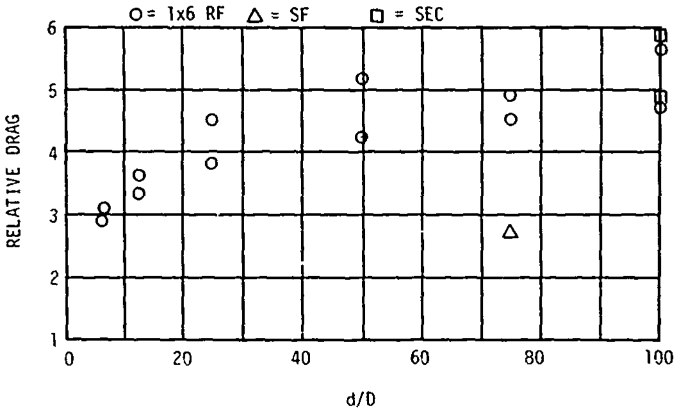


Figure 15a - Ribbons and Stubs

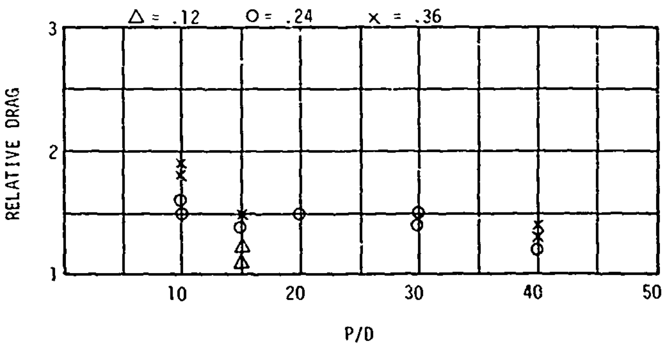


Figure 15b - Helical Wrap

Figure 15 - Tangential Drag of Selected SRD's Relative to a Bare Cable

TABLE 3 - RANKING OF STRUM REDUCTION DEVICES

SRD	dB Down	Description	Coverage
SEC	Largest	See Appendix A	100%
HW	12.5-13	P/D = 15, d/D = 0.24	100%
RF	12.5-13	1 x 6 & 1 x 4	25%
RF	11-13	2 x 6	12.5%
RF	12-13	1 x 6, Type I	25%
RF	13	1 x 6, Type II	12.5%
R/S	12.5	25/50	
SF	7-8	1 x 1/4	75%
Sleeves	3.5-4	Heavy	33.3%
Sleeves	2-3	Light	All
Rings	2	7.5 D spacing	-

TABLE 4 - TANGENTIAL DRAG OF SRD MODELS RELATIVE TO BARE CABLE

Speed of Tow					
10 knots (5.1 m/s)			15 knots (7.7 m/s)		
Type	Cov. %	Rel. Drag	Type	Cov. %	Rel. Drag
RF 1 x 6	100	5.6	SEC	100	5.9
RF 1 x 6	50	5.2	RF 1 x 16	100	4.7
RF 1 x 6	75	4.9	RF 1 x 6	75	4.6
SEC	100	4.9	RF 1 x 6	50	4.2
RF 1 x 6	25	4.5	RF 1 x 6	25	3.8
RF 1 x 6	12.5	3.6	RF 1 x 6	12.5	3.3
RF 1 x 6	6.25	3.1	RF 1 x 6	6.25	2.9
SF 1 x 1/4	75	2.7	SF 1 x 1/4	75	2.7
HW* .36, 10	100	1.9	HW* .36, 10	100	1.8
HW .24, 10	100	1.5	HW .24, 10	100	1.6
HW .24, 20	100	1.5	HW .36, 15	100	1.5
HW .36, 15	100	1.5	HW .24, 20	100	1.5
HW .24, 15	100	1.4	HW .24, 15	100	1.4
HW .24, 30	100	1.5	HW .24, 30	100	1.4
HW .36, 40	100	1.3	HW .36, 40	100	1.4
HW .24, 40	100	1.2	HW .24, 40	100	1.2
HW .12, 15	100	1.1	HW .12, 15	100	1.2

* Classified according to d/D and P/D, in the order shown.

In general, the helical wraps produce the smallest increase in drag. Of these, the drag is highest for the larger values of d/D and the lower values of P/D. The high coverage 1 x 6 ribbons and Seismic Engineering Corporation fairing give the largest increases in drag, whereas the stubs (75% coverage) and 6.25% and 12.5% coverage 1 x 6 ribbons produce intermediate values.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of these experiments, the following are concluded:

1. The experimental technique provides an economical, efficient method for evaluating the relative effectiveness of strum reduction devices.

2. The Seismic Engineering Corporation (SEC) fairing, ribbon fairing (RF) and helical wraps (HW) are all effective in the reduction of strum. The SEC fairing is more effective than the HW and RF.

3. The sleeves and rings produce only minor reductions in strum amplitude.

4. Stub Fairing (75% coverage) produces about one-half the strum reduction (in decibels) provided by RF and HW. This corresponds to an 80% reduction in strum amplitude, as compared to about 95% reduction for the HW and RF.

5. The use of HW, SF, RF and SEC type SRD's leads to increased tangential drag of the bare cable. The HW produces the smallest increase. The other SRD's produce larger increases in the order stated. The SEC fairing produces the largest tangential drag.

6. The degree of strum reduction required to reduce self-noise levels of a ship towed acoustic array to acceptable levels is unknown. It is therefore recommended that the ribbon, stubs, and helical wraps be evaluated at-sea for effectiveness in acoustic self-noise reduction.

APPENDIX A

DESCRIPTIONS OF STRUM REDUCTION DEVICES (SRD's)

REFERENCE CABLE

All models were fabricated from the double-armored cable described in Table A-1 and shown in Figure A-1.

TABLE A-1 BARE CABLE PARAMETERS

Manufacturer	United States Steel Corp.
Type	7J525A
Diameter	0.528 ± .0006 inch (13.4 ± .015 mm)
Construction	24 x 24 double armor
Number of Conductors	7
Weight in Air	0.427 pounds/foot (0.635 kg/m)
Breaking Strength	21,000 pounds ($9.3X10^4$N)

RIBBONS

Ribbons consist of thin, flexible strips which are attached to the bare cable by being inserted under one or two of the outer wires of the cable armor such that equal lengths protrude, as illustrated in Figure A-2. A ribbon is described by two parameters:

W - ribbon width in units of cable diameter

ℓ - length of one member of the ribbon pair in units of cable diameter

Thus a 1 x 6 ribbon is one that is 1 diameter in width, and 6 diameters in length. Four parameters are required to describe a ribboned cable. These are (in units of cable diameter):

N - the number of ribbons set side-by-side within a group

s - the spacing between the N ribbons

G - the length of a group

B - the spacing between groups

For this report, the convention

$W \times \ell \cdot (N \times s) \cdot (G \times B)$

is established to describe a ribboned cable.

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FIGURE A-1 - Bare Cable with Attached Tow Fitting

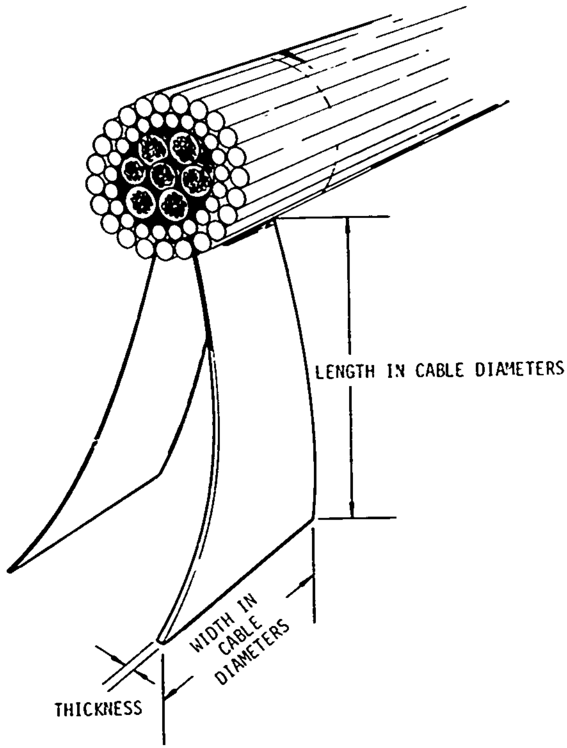


Figure A-2 - Sketch of Ribbon Attachment to Armored Cable

The coverage is defined as the fraction of the length of cable occupied by the ribbons. The inter-group coverage, C_G, is given by

$$C_G = \frac{NW}{NW + s} \tag{A.1}$$

and the overall coverage, C, by

$$C = \frac{C_G \; G}{G + B} \tag{A.2}$$

Three types of coverage are identified:

a) Regular - This type consists of a uniform repetition of the number of ribbons and their spacing. The group length and bare length designators may be dropped without ambiguity. The appearance of regularly spaced ribbon and the use of the description convention are illustrated in Figure A-3.

b) Type I Groupings - This type consists of a span of ribbons butted (i.e., s = 0) followed by a length of bare cable, B. The Type I group is illustrated in Figure A-4.

c) Type II Groupings - This type consists of groups of length G with inter-group coverage of less than 100%. Note that the group length designator implies that a space is associated with the last ribbon of the group. The Type II group is illustrated in Figure A-5.

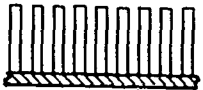
The models selected for evaluation are listed in Table A-2.

100% COVERAGE

$W \times \ell \cdot (Nxs) \cdot (GxB)$

$1 \times 6 \cdot (1x0) \cdot (1x0)$

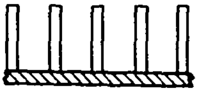
$$C_G = \frac{1 \times 1}{(1x1) + 0} = 1, \quad C = \frac{1 \times 1}{1 \times 0} = 1$$



50 COVERAGE

$1 \times 6 \cdot (1x1) \cdot (2x0)$

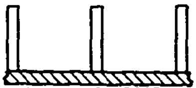
$$C_G = \frac{1 \times 1}{(1x1) + 1} = 0.5, \quad C = \frac{0.5 \times 2}{2 + 0} = 0.5$$



25 COVERAGE

$1 \times 6 \cdot (1x3) \cdot (4x0)$

$$C_G = \frac{1 \times 1}{(1x1) + 3} = 0.25, \quad C = \frac{0.25 \times 4}{4 + 0} = 0.25$$

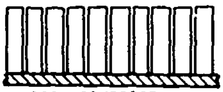


12.5 COVERAGE

$1 \times 6 \cdot (1x7) \cdot (8x0)$

$$C_G = \frac{1 \times 1}{(1x1) + 7} = 0.125, \quad C = \frac{0.125 \times 8}{8 + 0} = 0.125$$

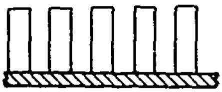
Figure A-3(a) - Examples of Regular (Uniformly Distributed) Coverage for 1 x 6 Ribbons



100 COVERAGE

$2 \times 6 \cdot (1x0) \cdot (2x0)$

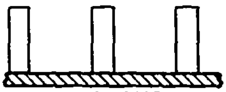
$$C_G = \frac{1 \times 2}{(1x2) + 0} = 1, \quad C = \frac{1 \times 2}{2 + 0} = 1$$



50 COVERAGE

$2 \times 6 \cdot (1x2) \cdot (4x0)$

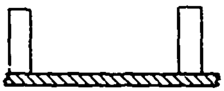
$$C_G = \frac{2 \times 1}{(2x1) + 2} = 0.5, \quad C = \frac{0.5 \times 4}{4 + 0} = 0.5$$



25 COVERAGE

$2 \times 6 \cdot (1x6) \cdot (8x0)$

$$C_G = \frac{1 \times 2}{(1x2) + 6} = 0.25, \quad C = \frac{0.25 \times 8}{8 + 0} = 0.25$$



12.5 COVERAGE

$2 \times 6 \cdot (1x14) \cdot (16x0)$

$$C_G = \frac{1 \times 2}{(1x2) + 14} = 0.125, \quad C = \frac{0.125 \times 16}{16 \times 0} = 0.125$$

Figure A-3(b) - Examples of Regular (Uniformly Distributed) Coverage for 2 x 6 Ribbons

Figure A-3 - Examples of Regular Type Ribbon Coverage

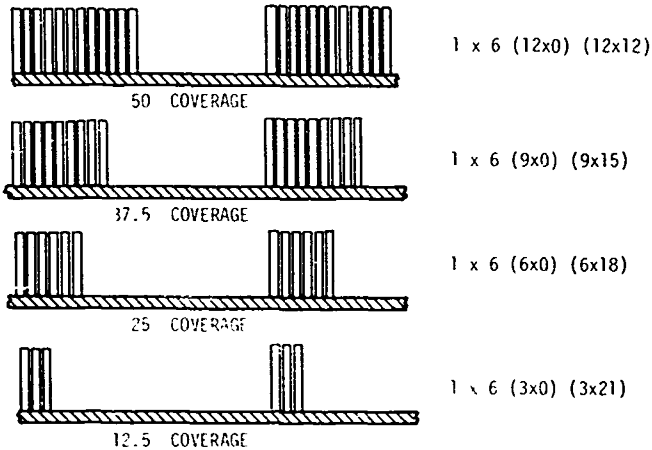


Figure A-4 - Examples of Various Coverages for Type I Groupings
1 x 6 Ribbons

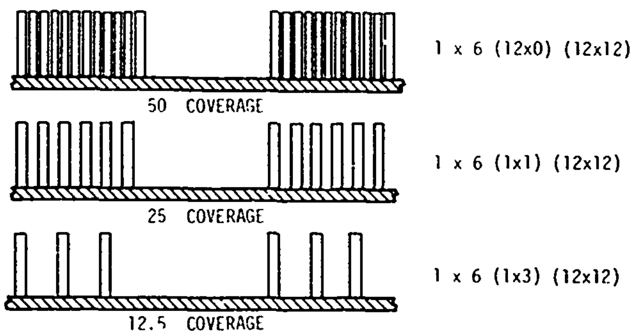


Figure A-5 - Examples of Various Coverages for Type II Groupings
1 x 6 Ribbons

TABLE A-2 RIBBON MODELS

COVERAGE - REGULAR					
(W x ℓ)	(N x s)	(G x B)	C_G %	C %	Figure
2 x 6	(1 x 1)	(3 x 0)	66.67	66.67	-
2 x 6	(1 x 2)	(4 x 0)	50	50	A-6
2 x 6	(1 x 6)	(8 x 0)	25	25	-
2 x 6	(1 x 14)	(16 x 0)	12.5	12.5	-
2 x 6	(1 x 30)	(32 x 0)	6.25	6.25	-
1 x 6	(1 x 0)	(1 x 0)	100	100	-
1 x 6	(3 x 1)	(4 x 0)	75	75	-
1 x 6	(1 x 1)	(2 x 0)	50	50	A-7
1 x 6	(1 x 7)	(8 x 0)	12.5	12.5	-
1 x 6	(1 x 15)	(16 x 0)	6.25	6.25	-
1 x 4	(1 x 0)	(1 x 0)	100	100	-
1 x 4	(3 x 1)	(4 x 0)	75	75	-
1 x 4	(1 x 1)	(2 x 0)	50	50	-
1 x 4	(1 x 3)	(4 x 0)	25	25	-
1 x 4	(1 x 7)	(8 x 0)	12.5	12.5	-
1 x 4	(1 x 15)	(16 x 0)	6.25	6.25	-

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FIGURE A-6 - 2 x 6 Ribboned Cable having a
Pattern (1 x 2) (4 x 0) for 50% coverage
(See Table A-2)

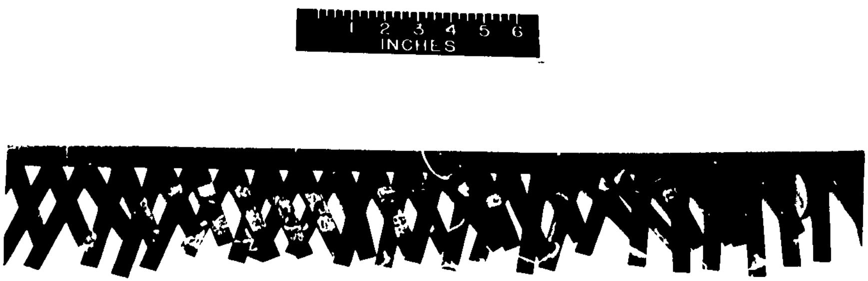

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FIGURE A-7 - 1 x 6 Ribboned Cable having a Pattern (1 x 1) (2 x 0) for 50% coverage (See Table A-2)

TABLE A-2 (Continued)

COVERAGE - TYPE I					
(W x ℓ)	(N x s)	(G x B)	C_G%	C%	Figure
1 x 6	(12 x 0)	(12 x 12)	100	50	-
1 x 6	(9 x 0)	(9 x 15)	100	37.5	-
1 x 6	(6 x 0)	(6 x 18)	100	25	
1 x 6	(3 x 0)	(3 x 21)	100	12.5	-
COVERAGE - TYPE II					
1 x 6	(12 x 0)	(12 x 12)	100	50	-
1 x 6	(1 x 1)	(12 x 12)	50	25	-
1 x 6	(1 x 3)	(12 x 12)	25	12.5	-

STUBS

"Stubs" are simply short ribbons. They may be formed by snipping the ribbons to the appropriate length. The convention for ribboned cable is applicable to stubs. The models evaluated are listed in Table A-3.

TABLE A-3 STUB MODELS

W x L	(N x s)	(G x B)	C_G%	C%	Figure
1 x 1/4	(3 x 1)	(4 x 0)	75	75	A-8
1 x 1/4	(1 x 1)	(2 x 0)	50	50	-
1 x 1/4	(1 x 3)	(4 x 0)	25	25	-

RIBBON/STUB COMBINATIONS

Cables were evaluated with combinations of ribbon and stub coverage. A ribboned cable with a specific coverage was altered by snipping ribbons to form stubs. The ribboned cables were of the regular coverage type, and were the 1 x 6 · (1 x 3) and 1 x 4 · (1 x 0) samples.* These cables had

* The (G x B) designation is dropped as no ambiguity results.

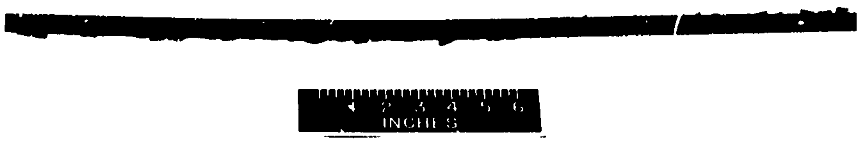

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FIGURE A-8 - 1 x 1/4 Stubbed Cable having a Pattern (3 x 1) (4 x 0) for 75% coverage (See Table A-3) originally 75% and 100% ribbon coverage, respectively. From the basic 75% distribution, every middle ribbon of the group of 3 was snipped to form a cable having a coverage of 50% ribbons and 25% stubs. From this model, every other ribbon is snipped to form a model having coverages of 25% ribbons and 50% stubs. Snipping every other one of the remaining ribbons obviously produces a cable with coverage of 12.5% ribbons and 62.5% stubs. The process is repeated until only stubs remain.

An ambiguity in the pattern is clearly possible for the 50% ribbon/25% stub combination. If the center ribbon in the group of 3 is cut, one obtains

R + S + R + s

where R stands for ribbon and S stands for stub. If the end ribbon is cut, one obtains

2R + S + s.

Therefore, for the ribbon/stub combinations (actually for any variation in ribbon length) the following convention is adopted:

(W x ℓ)R (W x ℓ)S (Pattern)

where the last group gives the pattern for a regular type coverage. The models evaluated are described in terms of this convention in Table A-4.

TABLE A-4 RIBBON/STUB COMBINATIONS

(W x ℓ)R	(W x ℓ)S	(Pattern)	(R/S) %
(1 x 6)R	(1 x ½)S	(3R + s)	(75/00)
(1 x 6)R	(1 x ½)S	(R + S + R + s)	(50/25)
(1 x 6)R	(1 x ½)S	(R + 2S + s)	(25/50)
(1 x 6)R	(1 x ¼)S	(R + 2S + s + 3S + s)	(12.5/62.5)
(1 x 6)R	(1 x ¼)S	(R + 2S + s + 3 (3S + s))	(6.25/68.75)
(1 x 6)R	(1 x ½)S	(3S + s)	(00/75)
(1 x 6)R	(1 x ½)S	(4R)	(100/00)
(1 x 6)R	(1 x ½)S	(3R + S)	(75/25)
(1 x 6)R	(1 x ¼)S	(R + 3S)	(25/75)

Note: R Ribbon S Stub S Space W Width ℓ Length

The symbol R/S is used to indicate the percentage coverage of ribbon and stub without regard as to distribution. The models covered with either all ribbons or all stubs are of course described by the more compact convention established earlier.

HELICAL WRAPS (HELICAL RIDGES)

Helical wraps are formed by twisting a wire about the test-cable in the form of a helix. The "wire" is actually a stranded rope of smaller diameter than the test cable and basically corresponds to the ridge types 1, 4 and 9 tested by Fabula in reference 1.

The parameters used to characterize a helically wrapped SRD are:

d/D - The ratio of the diameter of the wrapping wire, d, to the diameter of the sample cable, D.

P/D - The ratio of the pitch distance of the wrap, P (i.e., the linear distance along the sample cable in which the wrapping wire makes one full turn about the sample cable) to the diameter of the sample cable.

The models evaluated are listed in Table A-5.

TABLE A-5 HELICAL WRAPS

d/D	P/D	Figure
0.12	15	A-9
0.12	20	-
0.24	5	A-10
0.24	10	A-11
0.24	15	A-12
0.24	20	A-13
0.24	30	A-14
0.24	40	A-15
0.36	5	-
0.36	10	-
0.36	15	A-16
0.36	20	-
0.36	30	-
0.36	40	-

Single wraps only were evaluated. The direction of the lay of the wrapping cable was reversed at the mid-point.

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FIGURE A-9 - Spiral Wrap, $d/D = 0.12$, $P/D = 15$
(See Table A-5)

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FIGURE A-10 - Spiral Wrap, $d/D = 0.24$, $P/D = 5$

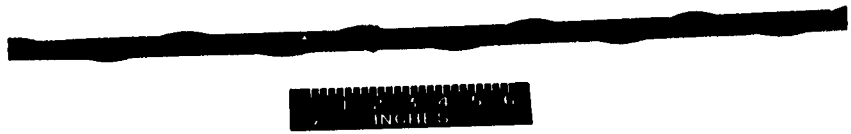

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FIGURE A-11 - Spiral Wrap, d/D = 0.24, P/D = 10

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FIGURE A-12 - Spiral Wrap, d/D = 0.24, P/D = 15

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FIGURE A-13 - Spiral Wrap, d/D = 0.24, P/D = 20

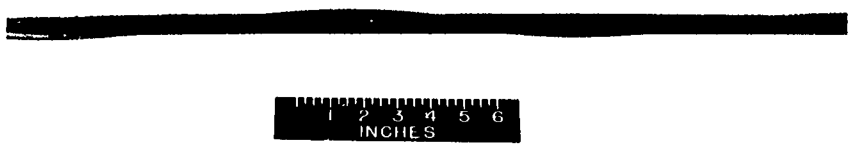

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FIGURE A-14 - Spiral Wrap, d/D = 0.24, P/D = 30

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FIGURE A-15 - Spiral Wrap, d/D = 0.24, P/D = 40

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FIGURE A-16 - Spiral Wrap, d/D = 0.36, P/D = 15

SLEEVES

A sleeve consists of a short length of tubing of larger diameter than the basic cable, fitted over the sample cable at periodic intervals of the cable length. The sleeves evaluated were characterized as "light" and "heavy." The light sleeves were fabricated from rubber and were essentially neutrally buoyant. The heavy sleeves were made of lead. Sleeves are characterized by the following parameters:

d_s/D - Ratio of sleeve outside diameter, d_s, to cable diameter, D.

μ - Ratio of total mass of sleeve plus cable (per unit length) to total mass of cable per unit length (including virtual mass).

L_s/L - Ratio of length of sleeve to total distance between starting point of the sleeves (for repetitively spaced sleeves).

The samples evaluated are listed in Table A-6.

TABLE A-6 SLEEVE MODELS

HEAVY SLEEVES			
d_s/D		1.42	
μ		3.25	
L_s	L	L_s/L	Figure
4 inches (102 mm)	16 inches (406 mm)	0.25	-
4 inches (102 mm)	12 inches (305 mm)	0.33	A-17
4 inches (102 mm)	8 inches (203 mm)	0.50	-
4 inches (102 mm)	Random	-	-
LIGHT SLEEVES			
d_s/D		1.42	
μ		1.19	
L_s	L	L_s/L	Figure
8 inches (203 mm)	18 inches (457 mm)	0.44	-
6 inches (152 mm)	18 inches (457 mm)	0.33	A-18
4 inches (102 mm)	18 inches (457 mm)	0.22	-
2 inches (51 mm)	18 inches (457 mm)	0.11	-

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FIGURE A-17 - Heavy Sleeves, $d_s/D = 1.42$, $L_s/L = 0.33$
(See Table A-6)

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FIGURE A-18 - Light Sleeve, $d_s/D = 1.42$, $L_s/L = 0.33$
(See Table A-6)

RINGS

The rings resemble square-cornered washers fitted to the cable at periodic intervals. The rings evaluated are described in Table A-7.

TABLE A-7 RINGS

Spacing	Spacing/D	Figure
Ring Diameter/D 1.42		
Ring Length/D 0.42		
12 inches (305 mm)	22.7	-
8 inches (203 mm)	15.2	-
6 inches (152 mm)	11.35	A-19
4 inches (102 mm)	7.6	A-20

SEISMIC FAIRING

The Seismic Engineering Company fairing shown in Figure A-21 was constructed of a fabric-reinforced rubber compound. The forward portion was doubled back and joined to the body to form an enclosure for the cable. The fairing was designed for a 0.70-to 0.75-inch (18-to 19 mm) diameter cable. The fairing was thus slightly over-size for the 0.53-inch (13.5 mm) diameter cable used for the experiments. The trailing flap was 3.35 inches (85 mm) long. The flap is cut such that it forms a rhombus. The acute angle of the rhombus was 17.5 degrees. The fairing was installed in 36-inch (0.91 m) long strips and prevented from sliding on the cable by the "stops" or clamps shown in Figure A-21.

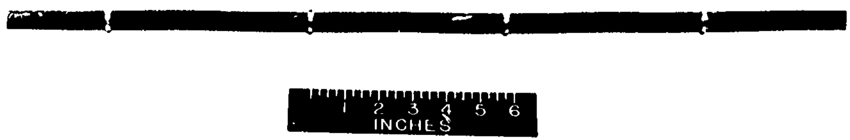

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FIGURE A-19 - Rings - Ring Diameter/D = 1.42
Ring Spacing/D = 11.35
(See Table A-7)

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FIGURE A-20 - Rings - Ring Diameter/D = 1.42
Ring Spacing/D = 7.6

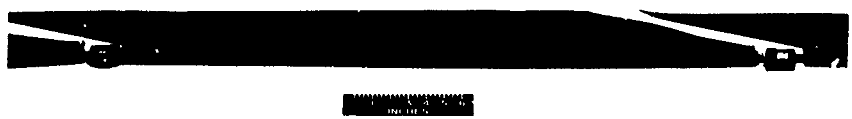

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FIGURE A-21 - Seismic Engineering Company Fairing

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